CONST-VIBRATION listserv Newsletter #21
Stresses in compliant (flexible) pipes can be calculated from peak particle velocities based upon the assumption that pipe and plane wave ground strains are equal

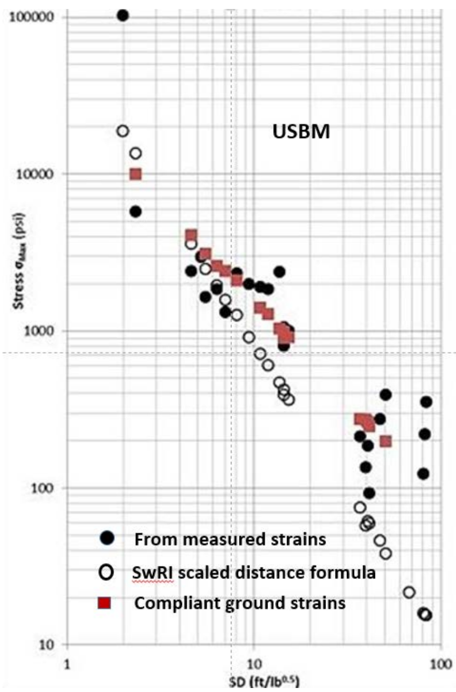

Figure 1 Comparison of stresses calculated with

1) measured longitudinal and hoop strains with biaxial stress-stain relationship (Filled circles)
2) SwRI empirical formula with distance, R, and charge weight, W (Open circles)
3) compliant (flexible) ground strain approach described in this newsletter (Red squares)

shows that control with peak particle velocity is possible with the compliant pipe ground strain, plane wave approach.

Integrity of pipe lines perturbed by vibratory ground motions is normally protected by limiting charge weights per delay or peak particle velocity (PPV). While control by measurement of induced stains would be more direct, the high cost and difficulty of strain measurement has led to reliance on an empirically based relation between maximum charge weight (and the associated PPV) and measured strain and calculated stress. This approach is based upon model tests where strains were measured in small diameter pipes in soil responding to blasts in soil (SwRI report by Westine et al, 1978). As described in Newsletter #20, subsequent field testing by the USBM has shown that the SwRI model based allowable PPV's are lower than those deduced from response of full sized pipes to blasts in rock.

This and subsequent Newsletters describes an approach for controlling strains and thus stresses by controlling PPV at the ground surface above the pipeline without use of the SwRI model tests in soil. Measured PPVs are converted to ground strains by division by the propagation velocity (PV), and ground strains are converted to pipe strains by the observation that ground and pipe strains are equal for sufficiently flexible pipes (forthcoming Newsletter #22). Pipe strains are then converted to pipe stresses through mechanics principles (forthcoming Newsletter #23). These blast induced stresses are then compared to the allowable percentages of Specified Minimum Yield Stress (SMYS) of the pipe.

Conversion of PPV to ground strain is based upon two principles; 1) ground motions produce no stress concentrations and 2) sufficiently flexible pipes deform with the ground. As described by Merritt et al (1985)., if the wave length is significantly longer than the buried structure diameter (D), stress concentration or wave reflections will not develop. Time histories in the USBM study (Newsletter #20) indicated that at scaled distances (SD) of 10 ft/$W^{1/2}$ the dominant frequency (f = 1/T) of the perturbing motion is 20 the 25 Hz. Thus the ratio of the wave length (PV*T) to the 3 ft diameter, D, of a typical steel transmission pipe, is for the USBM propagation velocity (PV) of 6,800 ft./sec

$$(PV*T)/D = (6{,}800\ ft/s*1/25)/3 = 90$$

With this large a ratio, the passing wave will hardly notice or interact with the pipe. This principle also can be stated in terms of ratios of rise time, ¼ T, to transit time, D/PV

$$(¼*1/f)/(D/PV)= (¼*1/25)/(3\ ft/7000\ ft/s) = 23$$

which is also so large as to produce no stress concentration.

Pipes flexible enough to deform with the ground have high flexibility ratios, F. The flexibility ratio, F, is the ratio of ground stiffness, $E_g/(1+\upsilon)$, to pipe stiffness, $6E_pI/(1-\upsilon^2)*1/R^3$ for states of pure shear is

$$F = E_g/(1+\upsilon) / ((6E_pI)/(1-\upsilon^2)*1/R^3)$$

where E_p = Young's Modulus of the pipe, υ=Poisson's Ratio, R = the pipe radius and I is the moment of inertia of the pipe (= $(1/12)*t^3b$) where b is a unit distance along the pipe axis. Peck et al (1972) demonstrate that pipes with F greater than 10 are sufficiently flexible. Thus 76 to 50 cm (30 to 20 in) diameter welded steel pipes, with F's of 60 and 30 are sufficiently flexible. USBM full scale field tests demonstrate that pipes with F's as low as 2.6 sustain the same strains as pipes with F's 30.

Conversion of PPV's to ground strains is based plane wave propagation. Plane wave PPVs can be converted to ground strains by division by the appropriate propagation velocity. Thus compressive and shear strains are equal to compressive and shear wave PPVs divided by the respective compressive and shear wave propagation velocity (Dowding, 1996). The plane wave assumption is most applicable for blasts at sufficiently large distances from the pipeline where the blast wave front has a relatively large radius of curvature.

Blasting close in to pipelines produces two major additional considerations: 1) small radii of curvature of the blast wave front that invalidates the plane wave assumption and 2) blast induced permanent rock block displacement. Blasting within a distance equal to twice the blast hole depth may place the pipe within the crater zone. Location of the pipe within crater zone increases the likelihood that rock blocks maybe permanently displaced by gas pressurization or back break. Such rock movement is not a vibration issue, but one that requires careful attention by the blaster.

Equality of stresses calculated from measured strains and those calculated by the compliant pipe method shown in Figure 1 for distances greater than twice the blast hole depth (SDs greater than 4) show that the compliant approach is viable for those distances. At smaller scaled distances, preservation of pipeline integrity also requires steps to avoid permanent rock black displacement, which is not a vibratory issue.

References

Westine, P. S., E. D. Esparza, and A. B. Wenzel, 1978. Analysis and Testing of Pipe Response to Buried Explosive Detonation, Southwest Research Institute, Report for Pipeline Research Committee, American Gas Association, July, 173 pp.

Merritt, J.L., Monsees, J.E., Hendron, A.J., Jr., 1985. Seismic design of underground structures. Proceedings of the 1985 Rapid Excavation Tunneling Conference, vol. 1, pp. 104-131.